NTIA TR-97-343

Assessment of Compatibility Between 25 and 12.5 kHz Channelized Marine VHF Radios

technical report

U.S. DEPARTMENT OF COMMERCE ● National Telecommunications and Information Administration

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Assessment of Compatibility Between 25 and 12.5 kHz Channelized Marine VHF Radios

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Executive Summary

The maritime mobile frequency band supports maritime communications worldwide. Appendix 18 of the ITU Radio Regulations (RR) defines the channels of the maritime mobile service. These channels support a variety of communication functions including: public correspondence, intership and ship-to-coast, coast- to-ship, port operations, calling and various safety purposes. Safety functions include distress, search and rescue, ship movement, navigation (bridge-to-bridge) communications, and maritime safety information broadcasts.

Additional maritime mobile channels are required to meet the growing demands for the above services in the near future, particularly the demand for digital services. To accommodate the old and new services demand for additional channels, the maritime mobile spectrum needs to be used more efficiently. Narrowbanding of the maritime mobile VHF band from 25 kHz to 12.5 or 6.25 kHz channel bandwidths is one possible solution to make more channels available. However, any technique must take into account factors such as continuing to make low-cost transceivers available to the general boating public and preserving interoperability with existing 25 kHz FM equipment. They must also consider the time period in which these targeted improvements can be achieved. Furthermore, any new technology used to reduce spectrum congestion and improve spectrum efficiency must be able to accommodate existing safety and distress communications.

The United States plans to submit a proposal in the upcoming 1997 World Radio Conference (WRC -97) to permit narrowbanding the maritime mobile VHF band. To support that proposal, the United States Coast Guard and the National Telecommunications and Information Administration (NTIA) conducted bench and radiated tests of 25 kHz (referred to as wideband) and 12.5 kHz (referred to as narrowband) channelized marine radios. Commercial and recreational grade wideband and narrowband radios were tested for susceptibility to intermodulation products and adjacent/interstitial channel interference, and for interoperability. The narrowband radios were prototype commercial grade radios that were not fully optimized for narrowband operation. In addition, a VTS ship transponder receiver (as defined in ITU-R M.825) was tested for susceptibility to adjacent channel interference.

The results of the intermodulation tests showed that commercial grade radios are less susceptible to intermodulation products than the recreational grade radios. The results of the adjacent/interstitial channel interference tests showed that the narrowband radios were less susceptible to adjacent /interstitial interference than the wideband radios, both commercial and recreational grade. The results of the VTS ship transponder tests showed that the transponder receiver performed well in the presence of adjacent channel interference. The results of the interoperability tests showed that the wideband radios are fully interoperable with narrowband radios, with a slight degradation in the operating range of a wideband receiver.

Although the results of the tests showed that the wideband and narrowband radios are interoperable, introducing narrowband radios into the existing 25 kHz environment must be carefully done to minimize the effects of adjacent channel interference on wideband receivers. This is especially true when the narrowband radio is operating on an interstitial channel ±12.5 kHz off-tuned from a regular 25 kHz channel. One method that would help, but not totally eliminate, adjacent channel interference is to ensure geographic separation between adjacently tuned narrowband radio transmitters and wideband receivers. However, this may not be achievable in the entire maritime band due to the fact that most of the frequency channels in the band are not exclusively assigned but shared among a variety of users in the band. Initially, implementing separation distances to allow narrowband operations could be done by those maritime users that have greater control over who uses their services and who can afford narrowband capable equipment.

The range of distances that would be needed for geographic separation for adjacently tuned wideband and narrowband radios were calculated based on data from the bench tests. The results show that for 12.5 kHz of frequency separation from a 25 watt transmitter, the wideband radio required about 12 nmi of separation and the narrowband radio required about 6 nmi of separation to satisfy the test requirements. These results indicate that the narrowband radio was more immune to adjacent channel interference than the wideband radio. The aforementioned separation distances assume minimal degradation in receiver sensitivity for the mobile units. Operational base stations should observe larger separation distances, especially if the working frequencies with mobile units are simplex. Interoperability distances based on data from the bench tests showed that the wideband receiver lost about 3 nmi of operating range when communicating with a narrowband radio, as compared to a wideband radio. The narrowband receiver did not suffer any degradation in operating range when communicating with the wideband transmitter, as compared to communicating with a narrowband transmitter.

Table of Contents

Section One
Introduction

1.1 Background

The maritime mobile frequency band (156-162 MHz) supports maritime communications worldwide. Appendix 18[1] of the ITU Radio Regulations (RR) defines the channels of the maritime mobile service. These channels support a variety of communication functions including: public correspondence, intership and ship-to-coast, coast- to-ship, port operations, calling and various safety purposes. Safety functions include distress, search and rescue, ship movement, navigation (bridge-to-bridge) communications, and maritime safety information broadcasts.

Although not used extensively, data communications are also available on some channels by arrangement between administrations. Provisions in Appendix 18 consider the use of high-speed data and facsimile transmissions. The Radio Regulations, primarily Articles 59[2] and 60[3], provide technical characteristics for these functions. Most communications in the maritime mobile service utilize analog FM techniques for voice communications, although requirements for digital information exchange are expected to increase in the future.

Public coast station operators have an increased need for additional spectrum with the introduction of semi-automatic and automatic direct dial services in the U.S. Administrations where these services have been introduced have generally seen an increase of 10-20 fold in the amount of ship-to-shore and shore-to-ship traffic. In order to facilitate the proper implementation of automated services, the need for additional operating channels is necessary.

In addition, administrations implementing modern vessel traffic services (VTSs) using such techniques as automated dependent surveillance (ADS) will need internationally compatible radio channels set aside for data transmission. This includes the exchange of traffic and harbor data. VTS systems will take advantage of evolving digital technology moving towards developing a "voiceless" VTS.

To accommodate the maritime mobile service needs for more channels, the maritime mobile band needs to be used more efficiently. Narrowbanding of the maritime mobile VHF band from 25 kHz to 12.5 or 6.25 kHz channel bandwidths is one possible solution to making more channels available to the services described above. However, this technique must take into account factors such as continuing to make low-cost transceivers available to the general boating public and preserving interoperability with existing 25 kHz FM equipment. They must also consider the time period in which these targeted improvements can be achieved.

Furthermore, any new technology used to reduce spectrum congestion and improve spectrum efficiency must be able to accommodate existing safety and distress communications. Channel plans and modulation schemes for both new and existing transceivers must be interoperable and capable of immediately participating in the VHF maritime distress and safety system if narrowbanding is implemented.

The United States will submit a proposal in the upcoming 1997 World Radio Conference (WRC -97) to permit narrowbanding the maritime mobile VHF band. To support that proposal, the United States Coast Guard and the National Telecommunications and Information Administration (NTIA) conducted bench and radiated tests of 25 and 12.5 kHz channelized marine radios. In addition, adjacent channel interference susceptibility tests were performed on a VTS-like transponder system. Reports documenting results of the bench and radiated tests were distributed to the maritime industry for review and comment through the Radio Technical Commission for Maritime Services (RTCM). This report summarizes the objectives, procedures, and results of both the radiated and bench tests.

The VHF radio and transponder bench and radiated test objectives, procedures, and results are discussed in the following sections. Radiated tests were performed in a maritime environment in the South Florida area during August 1996. The bench tests were completed in April 1996 at the ITS laboratory in Boulder, Colorado.

1.2 Test Objectives

The objectives when testing the VHF radios on a bench and in a maritime environment were to: 1) Determine the susceptibility of 12.5 and 25 kHz channelized radios to adjacent/interstitial channel interference, and 2) Evaluate the interoperability of the 12.5 and 25 kHz channelized radios. The bench tests also included testing the 25 and 12.5 kHz radio's susceptibility to intermodulation products. The objective of the intermodulation tests was to evaluate the radios susceptibility to 3rd and 5th order intermodulation products with pairs of frequencies located in the marine band and out-of the marine band. The objective of testing the transponder was to evaluate its performance in the presence of adjacent/interstitial channel interference.

During the radiated tests it was decided to perform additional tests beyond those described in the original test plan circulated through RTCM. The procedures used in those tests and their results are discussed in section 2.1.4 of this report.

1.3 Test Radios

Production radios used for testing were commercially available analog 25 kHz channelized marine FM radios. These 25 kHz radios included three commercial grade radios representative of the type used by commercial boaters and government agencies.

Most recreational boaters use less expensive low-end 25 kHz radios. These types of radios could possibly be more susceptible to interference and interoperability problems and were therefore also tested. NTIA purchased three fixed mount and two hand-held radios of these types from local retailers for testing.

One manufacturer supplied two prototype 12.5 kHz channelized radios for the tests, one was configured as a mobile and the other as a base unit. These radios are not yet commercially available.

The radios are identified by alphabetical code using letters A through K, manufacturers' names and model numbers are not included in this report. These radios are also identified in the bench test report using the same letter. The radio are categorized as either recreational or commercial grade radios and as either fixed-mount or handheld below in table 2-1.

The 25 kHz channelized radios will be referred to as wideband radios and the 12.5 kHz radios will be referred to as narrowband radios for the remainder of this report.

Table 2-1
Radio Description

Radio	Type	Grade
A	fixed-mount 25 kHz	recreational
B	fixed-mount 25 kHz	commercial
C	fixed-mount 25/12.5 kHz	commercial (prototype)
D	fixed-mount 25/12.5 kHz	commercial (prototype)
E	hand-held 25 kHz	recreational
F	fixed-mount 25 kHz	commercial
G	hand-held 25 kHz	recreational
H	fixed-mount 25 kHz	recreational
I	fixed-mount 25 kHz	recreational
J	fixed-mount 25/12.5 kHz	commercial (prototype)
K	fixed-mount 25 kHz	recreational

The tests were performed according to the radio's mode of operation (base or mobile) and their channel numbering plan (25 or 12.5 kHz). The proposed channel numbering plan used by the prototype 12.5/25 kHz radios is defined in ITU Study Group 8B document 8B-TEMP/6Rev.1 (Draft Revision of Recommendation ITU-RM.1084[4], "Improved Efficiency in the Use of the Band 156-174 MHz by Stations in the Maritime Mobile Service"). This proposed channel numbering plan was used in this report to denote the channels used for testing.

This recommendation was approved at the international Working Party 8B meeting held in November 1996 and was approved by Study Group 8 in June 1997.

Section Two
Test Results

2.1 Adjacent Signal Susceptibility Tests

The recorded data and test procedures used in the adjacent signal susceptibility bench and radiated tests are described in Appendix A. The following paragraphs summarize the results of the adjacent signal susceptibility tests.

2.1.1 Bench Tests

The results of adjacent signal interference bench tests show that wideband receivers are susceptible to narrowband interferers when the narrowband interferer is off-tuned ±12.5 kHz from the desired signal carrier. However, wideband receivers are less susceptible to narrowband interferers than wideband interferers when the narrowband interferers are off-tuned by at least 25 kHz from the desired signal carrier. For example, receiver A in Table A-1 required an interference power of -59 dBm from a wideband interferer off-tuned 25 kHz to degrade the SINAD from 15 to 12 dB but, as shown in Table A-2, -55 dBm was required for receiver A with a narrowband interferer off-tuned 25 kHz. Receiver A required 4 dB more of interference power from the narrowband interferer than the wideband interferer to degrade the SINAD from 15 to 12 dB. Although this number varies for each radio, it is true in all cases. Clearly, once the narrowband interferer is off-tuned 25 kHz and beyond, the narrow band interferer is less of a concern than the wideband interferer.

These results indicate that narrowband radio transmitters would not adversely affect wideband radio receivers operating 25 kHz and beyond from the narrowband transmitter. However, geographical separation or sharper filtering in the wideband receiver would be necessary if the wideband receiver was operating 12.5 kHz off-tuned from the narrowband transmitter. The cost of additional filtering in the receiver and tighter frequency tolerances should present only a moderate price increase to the overall cost of the radio.

The results of adjacent signal interference tests on narrowband receivers show they are less susceptible to wideband interferers than wideband receivers are to narrowband transmitters. For example, receiver A (a 25 kHz radio) in Table A-2 required an interference power of -97 dBm to degrade the SINAD from 15 to 12 dB when the narrowband interferer was off-tuned -12.5 kHz from the desired signal and -99 dBm for +12.5 kHz off-tuning. The desired signal power for a 15 dB SINAD for receiver A was -114 dBm. The resulting signal-to-interference (S/I) ratios are -17 and -15 dB.

Receiver C (a 12.5 kHz radio) in Table A-7 required an interference power of -86 dBm to degrade the SINAD from 15 to 12 dB for a wideband interferer off-tuned -12.5 kHz and -82 dBm for 12.5 kHz off-tuning. The desired signal power for a 15 dB SINAD for receiver C was -117 dBm. The resulting S/I ratios are -31 dB and -35 dB.

Comparing the S/I ratios of the wideband and narrowband receivers, it can be seen that the narrowband radio (receiver C) has 14 dB better immunity to the wideband interferer than the wideband radio (receiver A) has to the narrowband interferer. Although the S/I ratios are different for each receiver, this is true for all cases of wideband receivers versus the narrowband receiver.

These results indicate that narrowband receivers could operate in a wideband environment as well as wideband radios on 25 kHz channels but would require some geographical separation if they were operating on an interstitial channel 12.5 kHz off-tuned from a regular 25 kHz channel.

The geographical separation distances for adjacently tuned wideband and/or narrowband radios are discussed in section 2.1.3. The distances were calculated using the NTIA NLAMBDA computer propagation model for smooth earth at 50 percent.

2.1.2 Radiated Tests

The results of the adjacent signal interference susceptibility tests show that the narrowband radio was more immune to adjacent channel interference than the wideband radios. The S/I ratio for the narrowband radio was -35 dB whereas the best S/I ratio for the wideband radios (shown in Table A-11) was -10 dB, which was determined for receiver B. Receiver G had the worst S/I of +12. These results were expected and agreed with the results of the bench tests which also showed that the 12.5 kHz receiver with a narrower IF bandwidth is more immune to adjacent channel interference than current wideband radios.

2.1.3 Adjacent Channel Separation Distances

Average channel separation distances for a wideband receiver were calculated based on the separation distances for each wideband receiver. The distances were calculated for a wideband receiver versus adjacently tuned wideband and narrowband transmitters off-tuned by 25 kHz, and for a narrowband transmitter off-tuned by 12.5 kHz. The power of the adjacent transmitters was 25 watts and three cases of antenna heights were considered: 3 meters, 3 and 10 meters, and 10 meters. The distances were calculated based on the data in Tables A-1 and A-2 of Appendix A and the methodology described in Appendix E. The results are shown below in Table 2-1.

Table 2-1
Wideband Receiver Average Adjacent Channel Separation Distances (25w)

Antenna Heights	Δf=25 kHz		Δf=12.5 kHz
	25 watt 25 kHz Transmitter	25 watt 12.5 kHz Transmitter	25 watt 12.5 kHz Transmitter
H1=3 m H2=3 m	1.7 nmi	1.3 nmi	11.9 nmi
H1=3 m H2=10 m	1.9 nmi	1.7 nmi	12.6 nmi
H1=10 m H2=10m.	1.9 nmi	1.7 nmi	13.7 nmi

As shown in column three of Table 2-1, the separation distances for the wideband receivers versus a narrowband transmitter, off-tuned by 25 kHz, are equivalent to the separation distances for a wideband transmitter off-tuned by 25 kHz which are shown in column two. However, the separation distances for the wideband receiver increase when the narrowband transmitter is tuned to the adjacent interstitial channel. The maximum value is 13.7 nautical miles for a transmit and receive antenna height of 10 meters. The variability in the separation distances relative to the average values shown in Table 2-1 for the individual radios was about .4-1 nautical miles for the wideband and narrowband interferers off-tuned by 25 kHz and about 1.7-2.6 nautical miles for the narrowband interferer off-tuned by 12.5 kHz.

Separation distances for a 5 watt transmitter versus a wideband receiver are shown below in Table 2-2.

Table 2-2
Wideband Receiver Average Adjacent Channel Separation Distances (5w)

Antenna Heights	Δf=25 kHz		Δf=12.5 kHz
	5 watt 25 kHz Transmitter	5 watt 12.5 kHz Transmitter	5 watt 12.5 kHz Transmitter
H1=3 m H2=3 m	1.3 nmi	1.3 nmi	8.4 nmi
H1=3 m H2=10 m	1.3 nmi	1.3 nmi	9.0 nmi
H1=10 m H2=10 m	1.3 nmi	1.3 nmi	9.8 nmi

Separation distances for a 1 watt transmitter versus a wideband receiver are shown below in Table 2-3.

Table 2-3
Wideband Receiver Average Adjacent Channel Separation Distances (1w)

Antenna Heights	Δf=25 kHz		Δf=12.5 kHz
	1 watt 25 kHz Transmitter	1 watt 12.5 kHz Transmitter	1 watt 12.5 kHz Transmitter
H1=3 m H2=3 m	.9 nmi	.9 nmi	5.8 nmi
H1=3 m. H2=10 m.	.9 nmi	.9 nmi	6.3 nmi
H1=10 m H2=10 m.	.9 nmi	.9 nmi	6.9 nmi

Table 2-1 represents the situation for a fixed mount transmitter versus a wideband receiver. Tables 2-2 and 2-3 represent the situation for a handheld transmitter versus a wideband receiver. In addition, Tables 2-2 and 2-3 could also represent a wideband receiver versus a fixed transmitter limited to low power operation on certain channels.

Adjacent channel separation distances were also calculated for a narrowband receiver versus a wideband transmitter off-tuned by 12.5 kHz. The power of the adjacent transmitter was 25, 5, and 1 watt. Three cases of antenna heights were considered: 3 meters, 3 and 10 meters, and 10 meters. The distances were calculated based on the data in Table A-7 of Appendix A and the methodology described in Appendix E. The results are shown below in Table 2-4.

Table 2-4
Narrowband Receiver Adjacent Channel Separation Distances

Antenna Heights	Δf=12.5 kHz	Δf=12.5 kHz	Δf=12.5 kHz
	25 watt 25 kHz Transmitter	5 watt 25 kHz Transmitter	1 watt 25 kHz Transmitter
H1=3 m H2=3 m	6.2 nmi	4.3 nmi	3.0 nmi
H1=3 m H2=10 m	6.7 nmi	4.7 nmi	3.5 nmi
H1=10 m H2=10 m	7.1 nmi	5.2 nmi	3.5 nmi

Comparing the entries of column two in Table 2-4 and column four in Table 2-1 it can be seen that the narrowband receiver has a smaller separation distance versus a wideband transmitter off-tuned by 12.5 kHz than vice-versa. For example, the separation distance for the narrowband receiver versus the wideband transmitter for antenna heights of 10 meters is 7.1 nautical miles. However, in the case of the wideband receiver versus the narrowband transmitter off-tuned by 12.5 kHz (using the same antenna heights) the separation distance is 13.7 nautical miles. Clearly the prototype narrowband radio which uses 15 kHz wide IF filters is more immune to adjacent channel interference than current production wideband radios that employ wide band IF's. The narrowband radios could be made even further immune to adjacent channel interference if the IF bandwidths were reduced to 10 kHz.

2.1.4 Additional Radiated Tests

Additional radiated tests were conducted using voice as the modulating signal for both the interferer and desired signal transmitter. These tests were observed by attendees of the RTCM conference. The results of these tests showed that an adjacently tuned interferer modulated by voice could degrade performance of a voice communication link.

The results of the tests using voice-shaped noise versus voice as the modulating signal for the interferer cannot be directly compared. The radiated test with the voice-shaped noise as the interfering signal modulation used a 1 kHz tone to modulate the desired signal radio to conduct a SINAD test. The SINAD test is a quantitative test that has a set goal for its results, which in our tests was 15 dB without interference to 12 dB with interference. The radiated test with voice as the modulating signal for the interferer and the desired signal transmitter was a qualitative test with no direct measurement of voice or message intelligibility attempted.

The goal of the quantitative test was to introduce interference into the communication link which would lower the SINAD. Lowering of the SINAD indicates that the performance of the communication link has suffered some degradation. This was done by placing the vehicle containing the interferer radio at a specific geographical location. With the interference being put into the link, the 1 kHz tone could still be heard from the receiver being tested, along with noise in the background. The background noise was due to the interferer being modulated by the VSN. When the qualitative test was done with the interferer staying at that same location but using voice as a modulator, one would expect to hear voice as the background interference.

2.2 Interoperability Tests

The recorded data and test procedures used in the interoperability bench and radiated tests are described in Appendix B. The following paragraphs summarize the results of the interoperability tests.

2.2.1 Bench Tests

The results of the interoperability tests of a narrowband transmitter and wideband receivers varied from radio to radio. Radio F in Table B-1 required -116 dBm of power from a narrowband transmitter to produce a 15 dB SINAD and -116 dBm of power from a wideband transmitter. However, radio G required -110 dBm of power from a narrowband transmitter and -115 dBm of power from a wideband transmitter to produce a 15 dB SINAD in the receiver, a difference of 5 dB. The other radios in Table B-1 required more power from the narrowband transmitter than the wideband transmitter to produce the 15 dB SINAD.

In a marine environment, these differences in wideband receiver sensitivity to 25 and 12.5 kHz transmitters would equate to some wideband radios having a reduced operating range when communicating with narrowband radios. Some of this is due to the narrowband transmitter having a 2 kHz signal deviation while the wideband transmitter was set to a 3 kHz signal deviation. With a lesser signal deviation, the narrowband signal contained less energy for the wideband receiver to demodulate.

The results of the interoperability tests of a narrowband receiver with a wideband transmitter in Table B-2 showed that the narrowband radio receiver required -117 dBm from a narrowband transmitter and -119 dBm from a wideband transmitter to produce a 15 dB SINAD. Therefore, properly designed narrowband radio receivers should be compatible with wideband transmitters with little loss of operating range.

2.2.2 Radiated Tests

The results of the interoperability tests listed in Table 5-3 showed that the wideband receivers were compatible with the narrowband transmitter. The difference for the received desired signal power from the narrowband and wideband transmitters at the input to the radio being tested to achieve a 15 dB SINAD varied from 2 to 10 dB.

2.2.3 Interoperability Distances

Average interoperability distances for a wideband receiver (e.g., the distance at which a 15 dB SINAD can be attained) were calculated based on the interoperability distances for each wideband receiver. The distances were calculated for a wideband receiver communicating with wideband and narrowband radios transmitting at powers of 25, 5, and 1 watt for three cases of antenna heights: 3 meters, 3 and 10 meters, and 10 meters. The distances were calculated based on the desired signal powers contained in columns two and three of Table B-1 in Appendix B and the methodology described in Appendix E. The average interoperability distances, in nautical miles, for the wideband receivers communicating with wideband and narrowband transmitters are shown below in Table 2-5.

Table 2-5
Wideband Receiver Average Interoperability Distances

	Pt = 25 Watts		Pt= 5 Watts		Pt=1 Watt	
Antenna Heights	25 kHz Transmitter	12.5 kHz Transmitter	25 kHz Transmitter	12.5 kHz Transmitter	25 kHz Transmitter	12.5 kHz Transmitter
H1= 3 m H2= 3 m	26 nmi	23 nmi	20 nmi	18 nmi	15 nmi	13 nmi
H1= 3 m H2= 10 m	28 nmi	25 nmi	21 nmi	19 nmi	16 nmi	14 nmi
H1= 10 m H2= 10 m	29 nmi	26 nmi	23 nmi	20 nmi	17 nmi	15 nmi

As shown in columns two through six of Table 2-5, the wideband receiver will have a minimal loss of operating range when communicating with a narrowband transmitter, as compared to a wideband transmitter operating at the same power output and antenna heights. On average, the wideband receiver will only experience 2 to 3 nautical miles of degradation in operating range when communicating with the narrowband transmitter. The variability in the interoperability distances for the individual wideband radios relative to the averages shown in Table 2-5 was about 3.5 nautical miles for the wideband transmitter and about 3.5 miles for the narrowband transmitter.

Interoperability distances were also calculated for a narrowband receiver communicating with a wideband and a narrowband radio transmitting at powers of 25, 5, and 1 watt. Three antenna heights were considered: 3 meters, 3 and 10 meters, and 10 meters. The distances were calculated based on the desired signal powers contained in columns two and three of Table B-2 in Appendix B and the methodology described in Appendix E. The average interoperability distances, in nautical miles, for the narrowband receiver communicating with wideband and narrowband transmitters are shown below in Table 2-6.

Table 2-6
Narrowband Receiver Interoperability Distances

	Pt = 25 Watts		Pt= 5 Watts		Pt=1 Watt	
Antenna Heights	25 kHz Transmitter	12.5 kHz Transmitter	25 kHz Transmitter	12.5 kHz Transmitter	25 kHz Transmitter	12.5 kHz Transmitter
H1= 3 m H2= 3 m	29 nmi	27 nmi	23 nmi	21 nmi	17 nmi	15 nmi
H1= 3 m H2= 10 m	30 nmi	29 nmi	24 nmi	22 nmi	18 nmi	16 nmi
H1= 10 m H2= 10 m	32 nmi	30 nmi	25 nmi	23 nmi	19 nmi	17 nmi

As shown in columns two through six of Table 2-6, the narrowband receiver will not experience any loss of operating range when communicating with a wideband transmitter, as compared to a narrowband transmitter operating at the same output power and antenna heights.

These interoperability distances show that wideband receivers should be compatible with narrowband transmitters and vice-versa, with minimal effect on the operating range of either type of radio.

2.3 Intermodulation Susceptibility Tests

The recorded data and the procedures used to perform the intermodulation susceptibility tests are described in Appendix C. The following paragraphs summarize the results of the tests.

The results of the 3rd order intermodulation susceptibility tests with wideband receivers showed a wide range of intermodulation rejection (IMR) values between manufacturers and price range of radios. In addition, the IMR for each radio varied if the pairs of signals generating the intermodulation products were in the receiver's RF pass band, or out-of the receiver's RF pass band. For example, in Table C-1 receiver A (a recreational grade wideband radio) had an in-band IMR of -63 dB and from Table C-2 an out-of-band IMR of -68 dB. Receiver B, a commercial grade wideband radio, had an in-band IMR of -81 dB but saturated before a measurement could be made on the out-of-band IMR.

The results of these tests indicate that front-end filtering in the radios lessen their susceptibility to out-of-band signals that cause the intermodulation products in the radio receiver. Radio A's out-of-band response was 5 dB better than its in-band response. The amount of additional IMR rejection for the out-of-band signal pairs is dependent on the radio being tested.

A more important result is the difference between commercial grade and recreational grade radios for the in-band IMR response. In this case the difference between receivers A and B is 18 dB. In a maritime situation, this difference in IMR performance would translate into radio B having a greater operational range than radio A, when a paging transmitter (158.700 MHz) and a rail/dock transmitter (161.025 MHz) were active in the area. Although the IMR varied from radio to radio, the commercial grade radios always had a better IMR than the recreational grade radios in these tests.

The results of the 5th order intermodulation susceptibility tests with wideband receivers (shown in Tables C-3 and C-4) revealed that most radios, both commercial and recreational grade, saturated before the intermodulation effects could be generated and verified. This was true for the in-band and out-of-band signal pairs response. However, when a 5th order IMR was measured its value was better than the 3rd order IMR response. For example, radio A's 5th order IMR was 10 dB better than its 3rd order IMR for both the in-band and out-of-band signal pairs.

The results of the 3rd order intermodulation susceptibility tests with narrowband receivers (radio C in Tables C-1 and C-2) showed that it had a better in-band and out-of-band IMR than the recreational grade 25 kHz radios. As in the case of the 25 kHz radios, the out-of-band IMR was greater then the in-band IMR. The in-band IMR was measured to be -77 dB and the out-of-band IMR was -84 dB. These IMR's were on par with the commercial grade wideband radios. This result was not unexpected because the radio was a prototype of a commercial grade narrowband radio. The manufacturer claims that production narrowband radios will come close to a -90 dB IMR.

Recreational grade narrowband radios were not available for this test, but should be tested if they go into production. Currently, the FCC does not mandate IMR performance standards for marine VHF radios sold in the United States. Many European nations require that marine radios sold in their country adhere to the International Electrotechnical Commission (IEC) IMR specification of -68 dB[5]. This level was easily met by commercial grade radios in the tests but could be a problem for recreational grade radios.

2.4 VTS-Like Transponder Tests

The recorded data and the procedures used to perform the transponder tests are described in Appendix D. The following paragraphs summarize the results of the tests.

The results of the adjacent signal interference susceptibility tests on the transponder showed that the dominant interference mechanism was front end saturation of the transponder receiver. Receiver saturation generally occurs at high interference power levels which equates to a higher degree of immunity to interference.

These test results show that, with a strong desired signal, this particular VTS-like transponder receiver was able to operate within the system with a high degree of immunity to adjacent signal interference.

2.4.1 VTS-Like Transponder Adjacent Channel Separation Distances

The VTS-like transponder receiver operating on an interstitial channel would require less than one quarter of a nautical mile of separation from a transmitter operating on the adjacent regular marine channel (12.5 kHz of frequency separation). This assumes the VTS-like transponder receiver has a strong desired signal (-60 dBm) and the interferer radio is transmitting with an output power of 25 watts.

Section Three
Conclusions

3. Conclusions

From reviewing the results of the bench and radiated tests, it should be possible to introduce radios and/or VTS like systems on 12.5 kHz channels provided that proper frequency management techniques such as geographical separation and/or receiver standards are implemented. A further discussion of each topic is given in the following paragraphs.

Geographical separation is an option that accommodates narrowband operations for specific licensed and/or assigned marine VHF operations, such as public coast stations and government operations. Public coast stations are licensed by the FCC and protected to a 17 dBuV contour to prevent interference from occurring between competitors on adjacent sites/channels. Public coast station operators that have licenses on adjacent VHF channels in the same area could use the interstitial between them as data or communication channels. In cases where multiple coast station licensees operate in the same area, the interstitial channels could still be used as long as coordination is performed between the interested parties.

Government radio communications operations in certain frequency bands are internally coordinated and licensed, therefore implementation of 12.5 kHz channels by government users can be conducted by using proper frequency management techniques such as geographic separations and/or exclusive use of 12.5 kHz equipment. This situation is similar to the land mobile implementation of interstitial 12.5 kHz channels into the existing 25 kHz environment in the 162-174 MHz and 406-420 MHz frequency bands.

Separation distances based on bench test results show that to achieve electromagnetic compatibility with geographic separation, wideband radios with wide IF receivers would require about 11-13 nautical miles of separation from radios operating on adjacent narrowband channels. The receivers of the prototype narrowband radios with narrower IF bandwidths are more resistant to interference. These types of receivers would require about 6-7 nautical miles of geographic separation. These distances are based on a transmit power of 25 watts and would be smaller if the power was reduced. The receivers of the VTS-like transponders are even more resistant to interference and would require less than a quarter mile of geographic separation to achieve electromagnetic compatibility.

Receiver standards are another option that could help implement narrowband operations in the marine VHF band. Current wideband marine radios used in the tests employ IF bandwidths as wide as the channel spacing of 25 kHz. The prototype narrowband radios used in the tests were designed with 15 kHz wide IF's to be compatible with both wide band and narrowband operations. They were found to be less susceptible to adjacent channel interference than the current wideband designs that use wide IF filters. Future 25/12.5 kHz radios could be designed with narrower IF's for better performance in the presence of interference without sacrificing receiver sensitivity or range.

In addition, the manufacturer of the prototype narrowband radios has suggested that separate IF filters could be used on narrowband channels. The channel space of a narrowband channel is 12.5 kHz. The IF filter does not need to be as wide as the channel spacing and could be reduced to approximately 10 kHz. This would further reduce its susceptibility to adjacent channel interference.

Receiver intermodulation rejection standards could also be used by manufacturers as guidelines when developing future marine VHF radios.

References

1. International Telecommunication Union (ITU) Radio Regulations. Appendix 18, *Table of Transmitting Frequencies in the Band 156-174 MHz for Stations in the Maritime Mobile Service*, 1994.

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3.International Telecommunication Union (ITU) Radio Regulations. Article 60, *Special Rules to the Use of Frequencies in the Maritime Mobile Service*, 1994.

4. International Telecommunication Union (ITU) Recommendation ITU-RM 1084, *Improved Efficiency in the use of the band 156-174 MHz by Stations in the Maritime Mobile Service*, 1994.

5. International Electrotechnical Commission (IEC) draft IEC 1097-7, *Global Maritime and Distress and Safety System (GMDSS) Part 7: Shipborne VHF Radiotelephone Transmitter and Receiver- Operational and Performance Requirements, Methods of Testing and Required Test Results*, 1997.